NOAA National Ocean Service Remote Sensing Applications and Concept of Operations

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***Abstract*- The National Oceanic and Atmospheric Administration (NOAA) is the primary civilian ocean agency in the United States. To meet its mission, the agency addresses coastal and ocean challenges on a daily basis focusing on issues ranging from genomics to coastal inundation. Comprised of 11 programmatic lines, NOAA's National Ocean Service (NOS) has a wide-range set of inter-related challenges extending from management of estuaries and marine protected areas to operational oceanography and forecasting. To meet these challenges, remote sensing technologies play a critical role in the NOS' ability to assess, monitor, and predict changes in environmental and biogeochemical parameters which support specific applications. In this presentation, we identify NOS ocean and coastal remote sensing requirements and describe progress towards the unified concept of operations initiated in 2004. The processes used in key remote sensing applications areas are illustrated in terms of their end-to-end processing systems. Finally, we show how NOS partners with other agencies, academia, and industry to achieve its remote sensing mission most effectively.**

I. INTRODUCTION

NOAA's primary mission is to understand and predict changes in the Earth's environment and conserve and manage coastal and marine resources to meet our nation's economic, social and environmental needs. Four focus areas have been identified as strategic goals within NOAA: ecosystems, climate, weather and water, and commerce and transportation [1,2]. NOAA's National Ocean Service (NOS), one of six NOAA line offices, comprised of 11 programmatic lines, represents one of the most diverse operating units within NOAA (Figure 1, Appendix).

NOS' broad purview spans each of the NOAA mission goals. For two hundred years, the Office of Coast Survey has been mapping and charting the nation's shoreline and ocean bottom to ensure safe and efficient marine transportation. Today the information they collect using multi-beam sonar is being used by sister NOS programs to map coral reefs, identify benthic habitat, and model ocean dynamics. Along the coasts, NOS is applying remote sensing technologies to monitor harmful algal blooms, hypoxia, coral bleaching, contamination, land use changes and bathymetry, and making the connections to human health and quality of life. Extreme events such as hurricanes and other hazards, as well as coastal issues associated with climate change and sea level rise now require more explicit connections between NOS' conventional oceanographic data, products, and services and those obtained from NOAA's operational or NASA's research satellite systems.

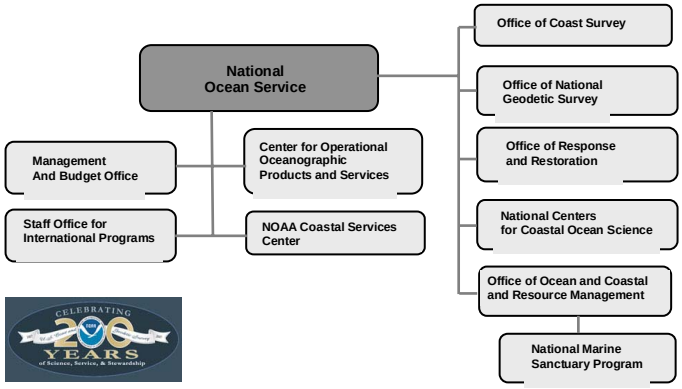

Figure 1. Science and service office structure of NOAA National Ocean Service.

Such a broad scope requires a systems approach to obtain data and deliver fully interpreted products and services, based on strong partnerships within NOS, the broader NOAA community, other agencies and customers. With over 152,000 km of coastline, 12 million sq kilometers in the Exclusive Economic Zone, 400,000 hectares of estuarine reserves in 23 states, and 240,000 sq km of marine sanctuaries and one national monument, NOS continues to be a substantial user of

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remotely sensed data to map and monitor its areas of responsibility.

II. NOS Remote Sensing Concept of Operations

To provide operational products and services to its constituents in a concerted and coordinated manner, NOS recognized the need for an internal remote sensing concept of operations. In 2004, prompted by many internal and external drivers, including recent national and international studies of the oceans and their coastal margins, NOS formed an interdisciplinary Remote Sensing Work Group (RSWG) to frame a truly enterprise concept of operations (CONOPS) [3]. The RSWG and the CONOPS allows remote sensing to more effectively contribute to the goals of NOS, NOAA, and the broader coastal and ocean community. Since the CONOPS is driven by its direct relevance to NOS' constituent requirements, the delivery of measurably improved and easily adopted products and services are better enabled.

Six "guiding principles" for unifying remote sensing in NOS were identified by the RSWG (Figure 2):

1. NOS employs one unified Concept of Operations for remote sensing that describes the specific end-to-end, data to service approach used in each of its primary remote sensing applications.
2. NOS constituents drive NOS' remote sensing priorities as documented in a consolidated requirements list.
3. NOS remote sensing products and services must be accessible, easily used by constituents, and cost efficient.
4. Enterprise coordination and communication is essential to collaboration within the agency and to the necessary partnerships with others.
5. NOS must improve its technology assessment and technology validation and verification in order to serve its constituents.
6. NOS must sustain and develop its scientific and technical capabilities to implement its Concept of Operations.

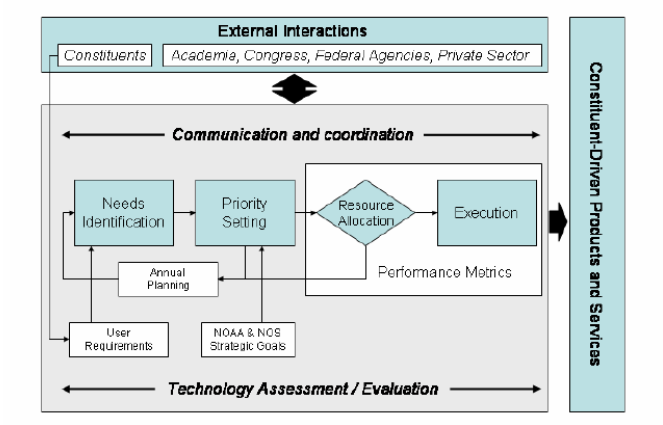


Figure 2. Diagram of the NOS Remote Sensing Operations Process

The purpose of the CONOPS is to implement these principles by adopting a consistent process that describes NOS remote sensing activities and capabilities including inputs, outputs, products, and outcomes. The basic information technology flow associated with each product and service is identified to show the critical path from data to product. Finally, intermediate and final graphic products are depicted and explained for the users. Using these steps, a portfolio of NOS products is being developed to communicate NOS remote sensing activities from research to operations. In addition to being a helpful outreach tool, this portfolio demonstrates the value of continual investments in critical ocean and coastal remote sensing data measurements in support of user needs.

III. User-Driven Remote Sensing Applications

A. *Requirements Drivers*

A range of remote sensing activities and related applied research are currently being conducted in order to meet the needs expressed by NOS constituents. Three examples of documents that help highlight the needs of NOS' user community include the U.S. Commission on Ocean Policy report [4], the Ocean Research Priorities Plan [5], and the NOAA Coastal Services Center's triennial Coastal Resource Management Customer Survey [6]. Additionally, many of NOS remote sensing products are generated to support mandated requirements set by legislative actions.

B. *Ecosystem goal*

The Harmful Algal Bloom Forecast System (HAB FS) is one of several NOS applications that use remote sensing technologies to address key issues within the Ecosystem mission goal area. As part of its mission to protect, restore and manage the use of coastal and ocean resources through ecosystem management approaches, NOAA has collaborated with state and local managers, and research scientists to provide nowcasts and forecasts of HABs to support public health officials, the seafood industry, coastal managers, and Chambers of Commerce.

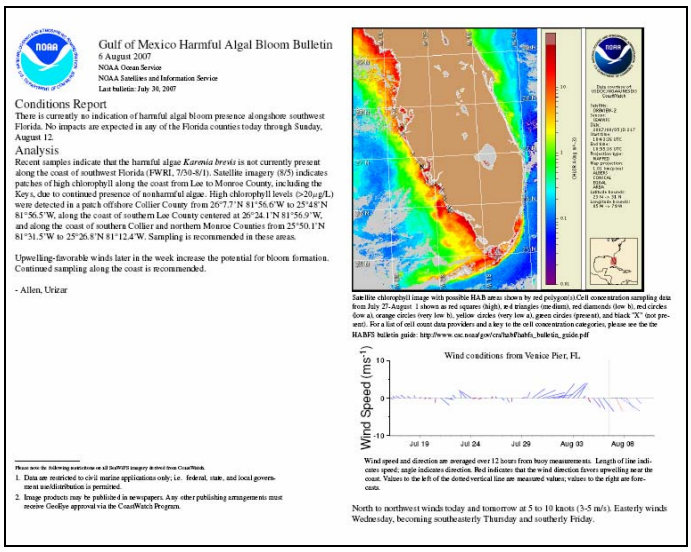


Figure 3. The HAB forecasts rely on ocean color imagery from the SeaWiFS satellite, in situ cell count data, real-time wind data from the National Data Buoy Center and modeled wind forecasts from the North American Mesoscale model.

Monitoring changes in coastal landscapes is also important to NOAA's Ecosystem mission goal. Coastal land cover change information, generated from remotely sensed data, can be used to monitor urban growth, map and inventory wetlands, uplands, and intertidal areas, delineate wildlife habitat, and develop trend analyses. In coordination with state coastal management agencies, the inter-agency Multi-Resolution Land Characteristics (MRLC) Consortium, and the U.S. Geological Survey (USGS), the NOAA Coastal Change Analysis Program (C-CAP) is providing products that are part of a nationally standardized database of land cover and change information, with one-to-five year updates, Figure 4 (http://www.csc.noaa.gov/crs/lca/ccap.html).

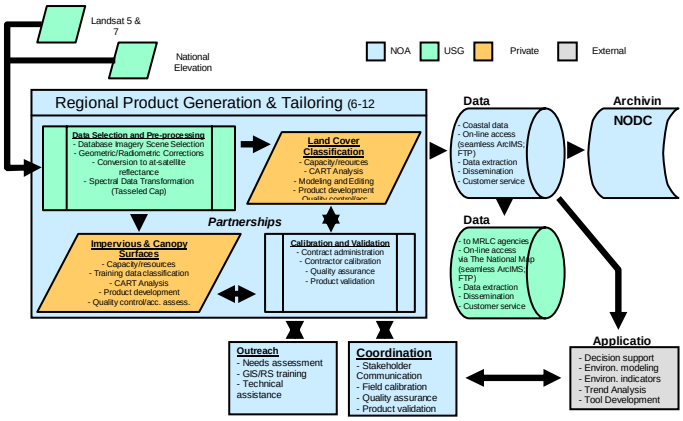


Figure 4. Data, processing steps and partnerships required to produce coastal change analysis products for wide range of users.

The data are derived from Landsat imagery and capture land cover on a regional scale, allowing users to effectively document changes over time, Figure 5.

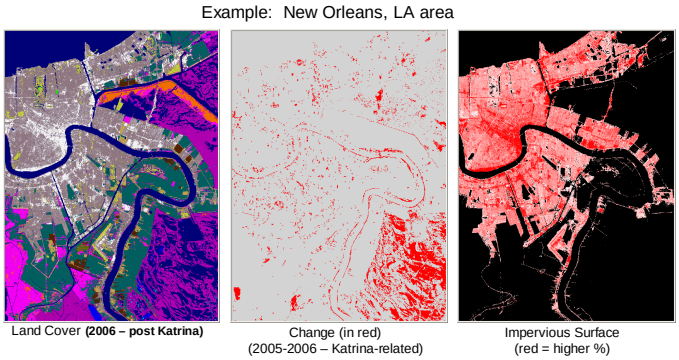


Figure 5. Land cover types, changes pre- and post- hurricane Katrina, and specific surface type products for New Orleans, Louisiana.

C. *Climate goal*

NOAA's Climate mission goal is to understand climate variability and change to enhance society's ability to plan and respond. The Coral Reef Watch program (http://coralreefwatch.noaa.gov/) provides data products that fall within the Ecosystem as well as the Climate goal areas. Satellite sea surface temperature (SST) images from the Advanced Very High Resolution Radiometer on NOAA's Polar Environmental Satellites are used to help predict the likelihood of mass coral bleaching events. Both intensity and duration of abnormally warm surface temperatures are used to help predict coral bleaching events. When a temperature anomaly reaches a critically high value or duration, the Coral Reef Watch program will issue an alert that a mass coral bleaching event may occur.

Topographic and bathymetric elevation products derived from light detection and ranging (LiDAR) data are used for various purposes within NOS, and are now becoming increasingly important for monitoring the impacts of climate change in the coastal environment. Various sources of remotely sensed imagery, such as aerial photography, satellite imagery, and backscatter from multibeam and LiDAR technologies, are used to develop digital, thematically accurate maps of U.S. shallow-water coral ecosystems to meet federal mandates, such as the Coral Reef Conservation Act and Magnuson-Stevens Act, and other requirements, Figure 6.

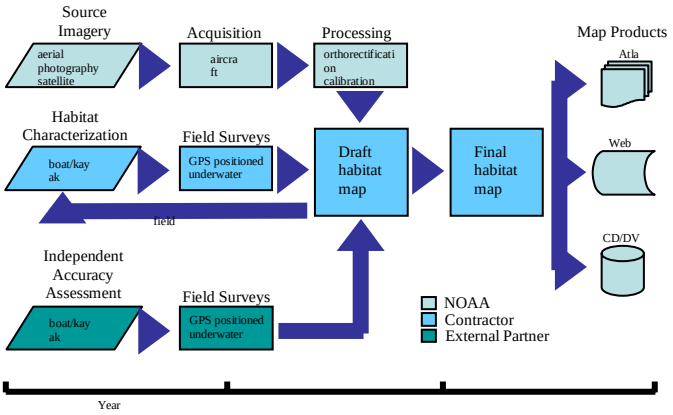


Figure 6. Data, processing steps and partnerships required to produce habitat characterization products for a wide range of users.

Two examples of habitat are a web site where all maps, imagery, and field data can be downloaded http://ccma.nos.noaa.gov/biogeography and a hard-copy, color Atlas showing the maps of an area.

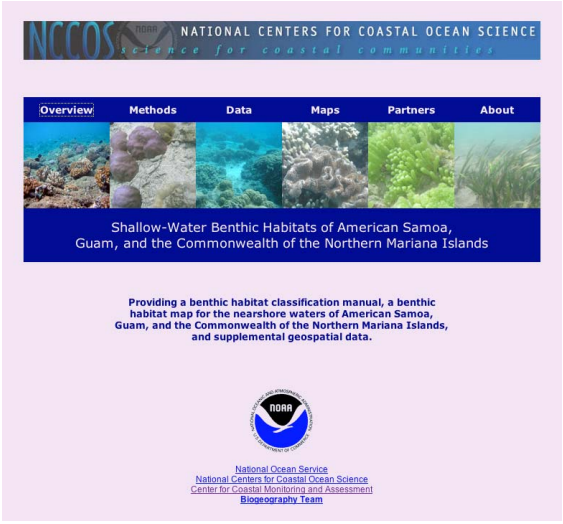


Figure 7. Digital, thematically accurate map products of U.S. shallow-water coral ecosystems provided in atlas format.

Sea level rise caused by the melting of the polar and Greenland sea ice has the potential to significantly alter the regional landscape. Lidar data have been shown to be extremely useful for visualizing both the physical and social impacts of sea level rise in the coastal zone. Lidar derived elevation products continue to provide vital information for floodplain and inundation mapping, monitoring shoreline changes associated with dune and cliff erosion, coastal watershed hydrologic applications, and the loss of protective wetlands.

D. Weather and Water Goal

Data products that meet the Weather and Water mission goal, to serve society's needs for weather and water information, include regional surface current forecasts provided throughout the US exclusive economic zone (EEZ). These surface current forecasts are provided through a distributed network of high frequency (HF) radars in cooperation with regional coastal ocean observing systems (RCOOS) as part of the Integrated Ocean Observing System (IOOS). The IOOS is an interagency, cooperative effort based on a network of buoys, ships, satellites, underwater vehicles and other platforms that routinely collect real-time data and manage historical information. The IOOS is the US contribution to the Global Earth Observation System of Systems, an international effort designed to monitor Earth and transmit observations globally.

NOS uses remotely sensed data such as aerial photographs and information about the biological and human use of shorelines to create Environmental Sensitivity Index (ESI) maps, Figure 8. ESI maps are useful for identifying sensitive resources before a hazardous spill occurs so that protection priorities can be established and cleanup strategies designed in advance.

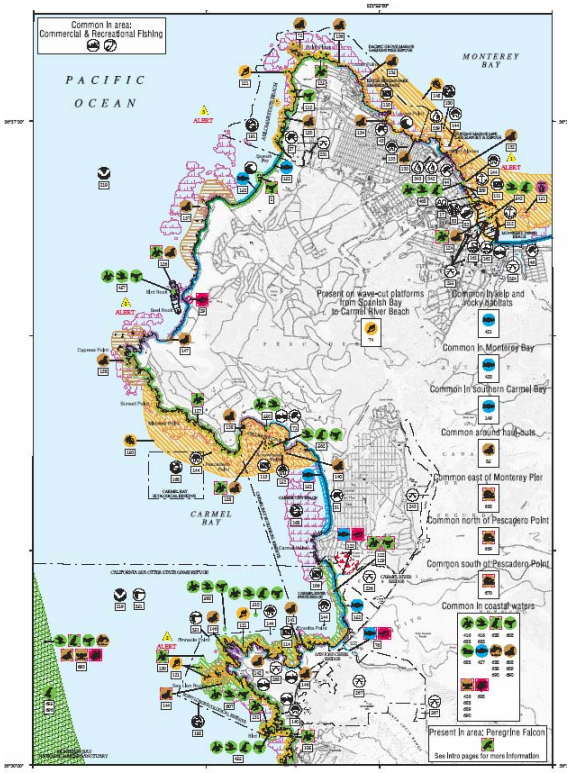


Figure 8. The Emergency Response Division of NOAA/NOS Office of Response and Restoration developed the most widely used approach to mapping the environmental sensitivity of coastal regions. This method systematically compiles information in standard formats for coastal shoreline sensitivity, biological resources and human-use resources into Environmental Sensitivity Index (ESI) maps.

This effort also addresses a critical need to monitor and predict habitat quality as part of the Ecosystem goal. Newer aerial digital imaging capabilities are also utilized in post-hurricane and other emergency response scenarios to provide initial visual assessments of damage and to help in response planning.

E. Commerce and Transportation goal

NOAA also develops products to ensure safe navigation in support of the Commerce and Transportation (C&T) mission goal, with the NOAA nautical chart likely being the most widely used product produced by NOS, Figures 9 and 10.

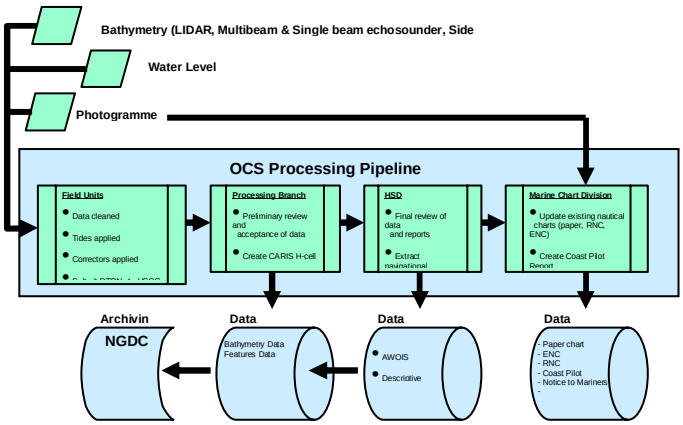
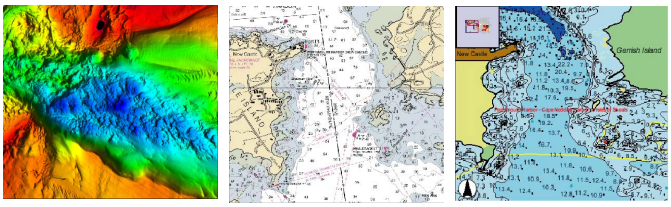


Figure 9. Data, processing steps and partnerships required to produce habitat characterization products for a wide range of users.

Remote sensing data from multi-beam acoustic surveys, for example, are one of the most essential pieces of information for charting coastal waterways and identifying geomorphic features and navigation hazards below the surface.



BASE Surface (Bathymetry) Approaches to Portsmouth, NH

Raster Nautical Chart (RNC) Approaches to Portsmouth, NH

Electronic Nautical Chart (ENC) Approaches to Portsmouth, NH

Figure 10. Hydrographic Surveys & Nautical Charts

These data can also provide valuable information about the habitat of certain fish species and other valuable benthic habitats such as submerged aquatic vegetation (SAV). The Integrated Ocean and Coastal Mapping (IOCM) initiative capitalizes on the C&T goal, and strives to "re-use" important data already collected from various programs and collect new data to support the needs of other goal areas, like the Ecosystem goal. By sharing important data and information from disparate programs within NOAA, comprehensive and coordinated maps characterizing not only the physical environment, but also the biological, geological, chemical and archaeological aspects of the marine environment can be realized. The IOCM initiative will provide new knowledge that is necessary for comprehensively characterizing our entire marine environment from top to bottom and throughout the EEZ

IV. CONCLUSIONS AND FUTURE WORK

The NOAA National Ocean Service is a diverse organization that serves science and technology-based products for a wide range of uses over many time and space scales. Corporate strategies for coordinating data collection, mapping, and charting activities are critical to the success of the organization and to its constituents' success, especially during this period of rapidly changing technology. The CONOPS plays an important role in coordinating NOS remotes sensing activities from the identification of user needs to the transition of information products and services to operational status. In our initial work with implementing a CONOPS approach, the NOS remote sensing working group found that the CONOPS depicts the necessary big-picture framework and critical pathways to ensure effective technology transfer and strategic partnerships.

Future projects demonstrating integrated coastal mapping across NOAA and with other federal agencies will take advantage of the collaborative philosophy of the CONOPS. Within this framework, the various offices within NOAA as well as external partners such as NASA, the Navy, and regional participants of the IOOS can align to achieve success through coordinated collaboration and targeted user needs with high-quality, focused end products. While an enterprise approach for addressing NOS remote sensing activities is crucial, NOS' remote sensing assets must also maintain the ability to adapt and undergo continual self scrutiny to improve its products and be prepared to address new and developing requirements. It will be through strategic alignment with NOAA goals and through partnerships, both internal and external, that NOS remote sensing products and services will achieve their greatest effectiveness.

APPENDIX

Brief Descriptions of the NOS Programs and Offices:

Office of Coast Survey: Responsible for managing a long-term hydrographic survey program to collect the hydrographic data required to produce and maintain the nation's 1,000 nautical charts. Recent initiatives include developing a full suite of Electronic Navigational Charts.

National Marine Sanctuary Program: Manages 13 national marine sanctuaries and one National Monument throughout U.S. coastal waters. Management includes regulatory authority, enforcement, monitoring and assessment, and an aggressive outreach and education program.

Office of National Geodetic Survey: Responsible for defining and managing the National Spatial Reference System (NSRS) that underlies the National Spatial Data Infrastructure (NSDI). Manages aerial photography of the nation's coasts to define the National Shoreline. Recent efforts include transferring technology and techniques to more accurately measure height (height modernization).Responsible for

defining the Spatial Reference System of the U.S. that underlies the Global Positioning System. Manages aerial photography of the nation's coasts to define shoreline. Recent efforts include transferring technology and techniques to more accurately measure height (height modernization).

Office of Response and Restoration: Responsible for emergency response to hazardous materials spills. Assesses damage from spills and waste sites and implements restoration plans. Lead office in NOAA's coral reef program. Leads cleanup operations on Pribilof Islands.

National Centers for Coastal Ocean Science Supports an applied science research program directed at managing coastal ecosystems. Program includes aspects of climate change, extreme natural events, pollution, invasive species, and land and resource use. Recent work includes ecological modeling to forecast Harmful Algal Blooms.

NOAA Coastal Services Center: Provides full range of services to coastal managers. These include many training programs, assessment of natural hazards, and many specialty products using advanced geographic information system technology.

Office of Ocean and Coastal Resource Management: Responsible for the nation's Coastal Zone Management Program by providing grants to 34 states. Oversees 25 National Estuarine Research Reserves in partnership with states. Manages NOAA's Marine Protected Areas Center. Runs Coastal and Estuarine Land Conservation Program.

Center for Operational Oceanographic Products and Services: Responsible for real-time tidal measurements and tidal forecasts. Maintains tidal histories and manages a real-time monitoring and modeling system to measure and predict tides and currents in major U.S. ports (PORTS).

International Programs Office: Works directly with major international organizations, such as IUCN and WCPA to transfer coastal management tools and techniques. Forms international partnerships to develop methods and procedures for measuring management effectiveness.

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